Water Air Soil Pollut: Focus (2007) 7:443–450
DOI 10.1007/s11267-006-9117-3

# National Greenhouse Gas Inventories: Understanding Uncertainties versus Potential for Improving Reliability

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Received: 12 May 2005 / Accepted: 24 February 2006 / Published online: 19 January 2007


**Abstract** We investigated the Austrian national greenhouse gas emission inventory to review the reliability and usability of such inventories. The overall uncertainty of the inventory (95% confidence interval) is just over 10% of total emissions, with nitrous oxide ($N_2O$) from soils clearly providing the largest impact. Trend uncertainty – the difference between 2 years – is only about five percentage points, as important sources like soil $N_2O$ are not expected to show different behavior between the years and thus exhibit a high covariance. The result is very typical for industrialized countries – subjective decisions by individuals during uncertainty assessment are responsible for most of the discrepancies among countries. Thus, uncertainty assessment cannot help to evaluate whether emission targets have been met. Instead, a more rigid emission accounting system that allows little individual flexibility is proposed to provide harmonized evaluation uninfluenced by the respective targets. Such an accounting system may increase uncertainty in terms of greenhouse gas fluxes to the atmosphere. More importantly, however, it will decrease uncertainty in intercountry comparisons and thus allow for fair burden sharing. Setting of post-Kyoto emission targets will require the independent evaluation of achievements. This can partly be achieved by the validation of emission inventories and thorough uncertainty assessment.

**Keywords** model uncertainty · Monte Carlo simulation · greenhouse gases · inventory quality considerations · Kyoto Protocol

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## 1 Introduction

Emission inventories are important tools for environmental policy. Typically covering material flows into the atmosphere, fluxes of atmospherically active substances (air pollutants or greenhouse gases [GHGs]) are accounted for as annual totals for specified regions. In general, the estimation of emissions follows guidelines that leave freedom for country-specific refinements (EEA 2004; Houghton et al. 1997). As direct measurements of emissions are rarely performed, the assessment of emissions from a single source is often based on the multiplication of a statistical parameter "activity" and the relation of this parameter to the emissions – the "emission factor." Even more complex variants of emission calculations (emission models) may be traced back to this simple concept (see, e.g., Webber and Fleming 2002). Greenhouse gas inventories, which also consider sinks of gases, do not explicitly refer to emissions or sources. The full amount of mass transfer into and from the atmosphere is not considered in all cases in

the inventory: international obligations to report national emissions fail to cover emissions from sources that are not considered attributable to a single nation. For example, international transport and natural emissions are not included in the national totals (UNFCCC 2004).

Increasing regulatory demands require improvements to be made to inventory quality. When a well-defined relationship exists between emissions (from a source) and the impact (on a receptor) of pollution, an emissions estimate provides a sufficient basis for regulatory action. Current research and policy issues of multicompound atmospheric chemistry, transboundary aspects of air pollution, or emissions trading require a much more intrinsic understanding of both the source–receptor relationship and the emission-generating processes. Consequently, efforts to improve emission inventories and to validate inventory output have been initiated, including an assessment of the reliability and uncertainty of inventories as part of these efforts (Penman et al. 2000).

The uncertainty of national greenhouse gas emissions as one component of quality improvement has been assessed for a number of countries (e.g., Monni et al. 2004; Winiwarter and Rypdal 2001). Using the experience gained from these studies, and interpreting the sensitivities associated with the quantitative assessment of uncertainties, a number of important conclusions can be drawn, including consequences for environmental policy.

## 2 Methodology: How to Assess the Uncertainty of National Emission Inventories

The assessment of the quality of any model result may take one of two different pathways:

1. Independent validation allows an unbiased assessment of model performance.
2. Sensitivity analysis, determining the uncertainty range of model input information and extrapolating to the variability of the output, is possible without independent information.

Because of the lack of independent validation data (such as emission estimates from inverse modeling of measured atmospheric concentrations), the quality of emission inventories can be fully covered at present only by investigating their input data.

In a study accompanying the official Austrian greenhouse gas emission inventory, all input information was systematically evaluated for its uncertainty (Winiwarter and Rypdal 2001). Both the magnitude and shape of the probability density functions were assessed using discrepancies between statistical data, measurements, or literature information as the main sources. Nevertheless, for a number of parameters no such reliable data was available. Structured interviews with experts in the respective sectors were used to obtain a well-documented expert estimate of the uncertainty elements of those parameters.

While this approach is fully able to cover the random variability of the underlying information, a potential systematic error (e.g., caused by methodological limitations) will not be detected. Such an error would, by its very nature, require correction at the time it is discovered; thus, it would not contribute to variability. In the above-mentioned study, systematic errors are assessed by not correcting data that is clearly erroneous. The difference between systematically wrong results and the new estimates is considered to represent systematic errors, assuming that any systematic error still remaining unidentified would be of the same size as those actually discovered.

The combination of uncertainties can be performed by error propagation or by Monte Carlo methods. While the application of error propagation has some theoretical limitations, the Monte Carlo approach requires more computing power, as it is based on random variations of the input parameters according to their respective probability density and on a statistical evaluation of the output. Considering the fairly simple computations involved in emission calculation, computing time is not a real issue, and the advantages of a Monte Carlo simulation, especially in terms of the treatment of covariance between two parameters (see below), become obvious. Sensitivity analysis demonstrates that – independently of the shape of the input probability functions – the output will approximate a normal distribution (Fig. 1).

## 3 Results

The uncertainty of an inventory can be expressed most conveniently as a percentage of total emissions. Following the guidelines of the Intergovernmental Panel on Climate Change (IPCC; Penman et al.